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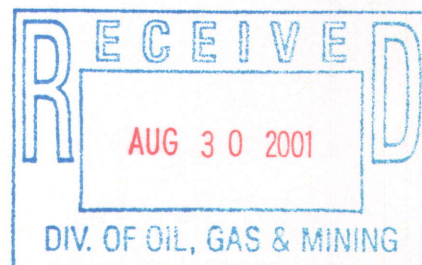
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Draft

South Facilities Groundwater

Remedial Design Work Plan For Geochemical  
Investigations: Tailings Disposal System

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Prepared By: Geochimica, Inc.

Date: August 27, 2001

Version A

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**KENNECOTT UTAH COPPER  
SOUTH FACILITIES GROUNDWATER  
REMEDIAL DESIGN**

**WORK PLAN FOR  
GEOCHEMICAL INVESTIGATIONS:  
TAILING DISPOSAL SYSTEM**

***DRAFT – VERSION A***

**Prepared for:**

**Kennecott Utah Copper Corporation**

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**Copperton, Utah \*\*\*\*\***

**Rev01e:2-May-01**

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## 1.0 INTRODUCTION

### 1.1 BACKGROUND

Kennecott Utah Copper Corporation (KUCC) has undertaken a program to manage water quality in parts of the southwestern Jordan Valley, Utah, where groundwater and surface water have been contaminated by mining activities associated with the Bingham Canyon mine. The remedy includes geologic, hydrologic, geochemical and engineering activities associated with three “functional units”:

- Groundwater containment and extraction system
- Water treatment (using nanofiltration and reverse-osmosis) and hydraulic delivery system for treated water and concentrate
- Management of the “Zone A” water-treatment concentrates in the KUCC tailing circuit.

This work plan directly addresses only the third part of the remediation. In addition to handling groundwater, the remedial program will manage meteoric water percolating through the Eastside waste-rock stockpiles and certain underground dewatering flows as part of the remedy. Some of these meteoric flows also are acidic and carry dissolved metals at concentrations greater than permitted discharge limits.

While the mine is operating, concentrate from the Zone A treatment system and the meteoric flows will be conveyed via the Copperton tailing line to the tailing-management facilities in Magna, where the flows and their chemical loads will report as part of the tailing stream to the North Tailing Impoundment. An innovative aspect of the proposed remedial action is the use of the Copperton tailing circuit to neutralize acidity and remove metals and metalloids from solution.

To date, laboratory test work, monitoring and modeling have not addressed the specific mechanisms of metals removal in the tailing circuit, the short-term or long-term geochemical stability of the metals from this waste stream in the tailing environment, the full-scale addition of the groundwater treatment streams to the tailing circuit, or potential for long-term accumulation of solutes in the system which could affect water quality of the process-water supply system for the Copperton Concentrator. KUCC has retained Mark J. Logsdon, Principal Geochemist of Geochimica, Inc. (Ojai, California), to help company staff develop and execute the remedial design and remedial action needed to comply with the USEPA Record of Decision that addresses the current groundwater contamination.

## 1.2 PURPOSE AND OBJECTIVES

The purpose of this Work Plan is to identify the geochemical and hydrogeochemical investigations needed to finalize technical aspects of the tailing-system disposal plans.

Specific objectives of the Work Plan include identification of:

- Scope and technical approach to the proposed geochemical studies
- Scope of work for the geochemical investigations
- Sampling and analysis plan for the geochemical investigations.

## **2.0 TECHNICAL APPROACH**

The geochemical issues associated with the tailing system are not self-evident and cannot be resolved by bulk-chemical analyses and simple mass-balance calculations alone.

KUCC's program will require some specialized sampling procedures and similarly specialized geochemical and computer-modeling techniques to: 1) determine the specific mechanisms of metals removal in the tailing circuit, 2) evaluate the short-term and long-term geochemical stability of the metals from this waste stream in the tailing environment, 3) address consequences of full-scale addition of the groundwater treatment streams to the tailing circuit, and 4) determine the potential for long-term accumulation of solutes in the system that could affect water quality of the process-water supply system for the Copperton Concentrator.

The technical approach to the study includes the following elements:

1. Description of the existing treatment system and its planned enhancements.
2. Documentation of the hydraulic design and performance of the Copperton tailing line and the tailing disposal system.
3. Characterization of the general flow field(s) in the tailing system.
4. Description of the mineralogy of tailing and chemistry of tailing slurry.
5. Determination of the geochemical mechanisms responsible for changes in chemistry in the disposal system, including in the tailing of the North Impoundment.
6. Development of a quantitative model for the geochemical evolution of the tailing system as treatment progresses.

### 3.0 SCOPE OF WORK

- Task 1. Compile existing databases and other information on groundwater hydrology and chemistry, tailing chemistry and mineralogy, mine planning, water treatment, and physical and chemical performance of the tailing system.
- Task 2. Document and evaluate the existing groundwater flow and transport model(s) and the existing mass-balance model for the tailing circuit.
- Task 3. Develop (or elaborate) a conceptual model for the tailing-disposal system. The conceptual model should be carried through to an initial identification of the constitutive relationships that would be part of a mathematical model and the identification of methods to solve the mathematical relationships. The existing STELLA model will be used to the extent practicable.
- Task 4. Develop and implement a sampling and analysis plan for: (a) tailing mineralogy and geochemistry (including the mineralogy and geochemistry of scale formation in pipelines); (b) tailing slurry solutions and other liquid inputs to the tailing pipelines; (c) pore water in both saturated and vadose zones of the deposited tailing; (d) decant solutions; (e) tailing solids in the saturated and vadose zones; and (f) hydraulic parameters for the saturated and vadose zones.
- Task 5. Analyze the tailing system hydraulics including (a) flow in pipelines; (b) hydraulic conditions and processes in the saturated zone(s); (c) hydraulic conditions and processes in the vadose zone; and (d) fluid recycling.
- Task 6. Examine the mineralogy and geochemistry of tailing solids and pipeline scale.
- Task 7. Analyze the chemistry of solutions.
- Task 8. Evaluate geochemical mechanisms for fluid and solid changes.
- Task 9. Develop and calibrate one or more quantitative models for the geochemical evolution of fluids and solids in the tailing system as a function of operational conditions and time.
- Task 10. Prepare reports (including portions of the Final Remedial Design).

## 4.0 SAMPLING AND ANALYSIS PLAN FOR HYDROGEOCHEMICAL STUDIES

Geochemical studies of the tailing disposal system (Tasks 5-9 above) will include five major evaluations:

- Characterization of source fluids (treatment concentrates; meteoric leach waters, and the aqueous phase of GMT tailing slurry) and solids (GMT tailing solids) prior to reaction in the pipeline;
- Chemical and mineralogical evaluation of the pipeline reactions;
- Hydrogeochemical modeling of the pipeline reactor;
- Geochemical evaluation of tailing (solids and water) in the impoundment;
- Monte Carlo simulation modeling of the tailing disposal system, including return flows.

### 4.1 SOURCE CHARACTERIZATION

1. ***Aqueous chemistry of treatment concentrates*** will be monitored by KUCC as part of the RD development and throughout the operational history of the remedial program. [*Meteoric leach flows* already are part of KUCC's routine water-quality monitoring program.] Chemistry of make-up water and process reagents also is available as part of ongoing programs. Finally, quality-control testing of the concentrates and meteoric flows will be part of the standard protocols for the treatment-program monitoring, and therefore would not further burden the tailing study during remedial design.
2. ***Tailing-solids bulk chemistry*** will be analyzed on splits of General Mill Tails (GMT) samples. Over the RD study period in 2001 – 2002, it assumed that the ore feed will change as KUCC mines through different lithologies and mineralogical alteration sequences in the pit. These changes need to be documented as part of the source-term characterization, and also to help understand how changes in the mine plan and mining sequence may affect tailing chemistry and mineralogy. The analytical program would have two parts:
  - a. ***Analysis of bulk tailing over time.*** During the RD process, a total of 50 GMT samples will be collected for bulk chemical analysis for parameters listed in Table 2, which includes acid-base characterization. The sample handling procedures for splits are discussed below.
    - Twenty (20) of the GMT tailing samples will be evaluated through a suite of selective extractions, intended to determine the distribution of trace metals with different possible mineral fractions in the tailing. Each sample will be dried with metals to be extracted from the as-received fraction of GMT. A example set of extractions, used in a geochemical study of another southwestern porphyry copper, follows (Ficklin et al., 1991):

1. *Carbonates*. Approximately 1 g of sample placed in a plastic centrifuge tube. Carbonate minerals dissolved with 20 mL of 1M acetic acid – sodium acetate buffer at pH 5. Tubes left standing for 1 hour, then capped and agitated for 4 hours. Aqueous phase separated by centrifuging at 15,000 rpm for 10 minutes.
2. *Manganese oxides*. Manganese oxides using 25 mL of 0.1 N hydroxylamine hydrochloride ( $\text{NH}_2\text{OH}\cdot\text{HCl}$ ) and 0.1=01 N  $\text{HNO}_3$ , shaking for 20 minutes.
3. *Amorphous iron oxides*. Amorphous iron oxides dissolved with 25 mL of 0.25 M  $\text{NH}_2\text{OH}\cdot\text{HCl}$  and 0.25 N HCL, heated to 70 °C in shaking water bath for 30 minutes.
4. *Crystalline iron oxides*. Crystalline iron oxides dissolved with 25 mL of 4.0 N HCl heated to 90 °C in a water bath.
5. *Residual metals*. Residual metals in silicates released by treating the residue of Step 4 using KUCC's standard four-acid digestion and evaporating to near dryness. The resulting product is dissolved in 0.5 N  $\text{HNO}_3$ .

The specific extractions to be used will be reviewed and updated after the initial mineralogical examination to optimize the extraction chemistry in light of the observed mineralogy. The relative contributions of the different mineral fractions to metals release can be determined algebraically once the entire suite of tests has been completed. Experience in other projects (David Blowes, personal communication, 2001; Carol Ptacek, personal communication, 2001) shows that the method of selective extractions, conditioned on mineralogy and with algebraic evaluation, avoids certain analytical and quality-control problems (e.g., solution carry—over from step-to-step) commonly associated with sequential extraction methods. KUCC's experience with tailing shows that a four-acid procedure (rather than the three-acid procedure of Ficklin) is needed for these materials.

After a final set of methods has been identified, Geochimica will document the test protocols and, in conjunction with Kennecott Environmental Laboratory, develop a set of QA/QC procedures designed to evaluate the variability of test materials as well as the reproducibility of extraction steps.

- The remaining thirty (30) samples will be analyzed only at the total digestion (multiple strong-acid) step (e.g., Step 5 of the Ficklin approach, above).
- b. Quality control. The solids analyses will follow KEL's standard QA/QC protocols. As stated above, a specific QA/QC protocol for the selective extractions will be developed after the most effective procedures have been identified.

3. **Tailing mineralogy.** The reactive capacity of the tailing depends primarily on the specific mineralogy of the tailing, and in particular on minor and trace phases, such as carbonates and oxides among the tailing solids. Experience in other tailing systems indicates that detailed mineralogical analyses are needed to identify and quantify such potentially reactive phases. Ten of the 50 samples will be sampled for mineralogy of GMT tailing (i.e. before reactions in the tailing line with water-treatment concentrates). The mineralogical samples will be prepared and evaluated by Dr. John Jambor (or by Mark Logsdon under Dr. Jambor's supervision) in the facilities of Leslie Investments Ltd. – Research and Development Division (Tsawassen, British Columbia) and the University of British Columbia (Vancouver, British Columbia). [Dr. Jambor's *curriculum vitae* is attached.] Evaluations will begin with optical petrography of both opaque and non-opaque phases. Splits of samples also will be subjected to x-ray diffractometry (XRD) of bulk powders. If analysis indicates significant clay-mineral contents, selected samples will be glycolated and subsequently heated to evaluate the clay minerals. Samples with high carbonate contents also may be re-analyzed after HCl treatment to dissolve the carbonates. Also, if the optical evaluations indicate that it would be advantageous, Dr. Jambor may select samples for Debye-Sherrer x-ray analyses to identify specific key phases. Selected portions of samples will be examined by electron microprobe in wavelength dispersion mode and by scanning electron microscopy (SEM) with energy dispersive analysis to determine mineral compositions and evaluate textures and, if present, rims or other alteration zones.
4. **Aqueous inputs.** Flows to the tailing line will be measured and analyzed at Stations BYP2537 (Mine Water); BYP2573 (Copperton Reservoir); BYP2538 (Wastewater Discharge Pump Station); and BYP2535 (Water Treatment Plant Concentrates). Analyses will be performed at Kennecott Environmental Laboratory for parameters in Table 1.
5. **Tailing-slurry fluid.** Samples of GMT tailing fluid will be collected at the thickener overflow splitter, before any concentrates or other mine waters have entered the pipeline. Samples of these fluids will be collected at the same time that specific tailing-solids are being sampled. Analyses will be performed at Kennecott Environmental Laboratory for the same parameters listed in Table 1.



## 4.2 CHEMICAL AND MINERALOGICAL STUDIES

The RD Work Plan needs to address four, related questions:

- What reactions occur in the tailing pipeline to neutralize acidity and remove metals and metalloids from solution?
- How stable will the reaction products be in the tailing impoundment in the short and long terms?
- Is there a rate of acid-water flux that would deplete the inherent neutralization potential tailing to the extent that there would be a significantly increased potential for future acidification and release of metals?
- Is it likely that the mass of gypsum and/or soluble metals (such as aluminum or manganese) added to the tailing from the acidic plume water would inhibit plant growth needed for revegetation of the tailing?

To address these questions both completely and in a time-sensitive manner, we propose both short-term, batch-mode testing and longer-term kinetic and field-scale testing.

### 4.2.1 Short-Term, Batch-Mode Testing

It may take years or even tens of years for geochemical problems to develop in full-scale tailing that could be sampled by lysimeters or other real-time monitoring sites in the impoundments. Kennecott needs a more rapid, scoping analysis of potential geochemical concerns that can be used for decision-making before large volumes of potentially reactive tailing already have been deposited. The following program of short-term testing will be performed early in the RD process (in CY 2001), so that KUCC can (a) identify potentially significant impacts, and (b) develop a simple tool, such as a “mixing table”, that can be used by both Kennecott’s mine planning and the environmental groups to ensure that adverse impacts to the long-term behavior of tailing will not occur.

The KUCC project team will collect approximately 20 tailing samples that exhibit a variety of acid:base accounting characteristics and that are composed of a mix of different ore types, based on information provided by KUCC geology and mine-planning personnel. [To the extent practicable, this set of 20 samples will be a subset of the total of 50 samples of tailing identified in Section 4.1 above.] Samples may include both current slurries and archived samples of GMT tailing (if such archival samples exist) to evaluate a range of tailing chemistries. Sub-samples from each of these tailing samples would then be mixed with various ratios of acidic treatment system and/or mine dump ARD water. Four of the 20 samples would be tested using replicate splits of tailing. In addition, four control samples, collected across the ABA range of the full 20-sample suite, would be tested by adding ASTM Type D, de-ionized water in lieu of acidic plume water. In eight of the 20 samples, lime (from the Concentrator source supply) would be added to the mixtures at two different dosages to evaluate the impacts of lime addition in the tailing pipeline.

After the materials have reacted for 4 hours (or another time to be determined by tracer tests of hydraulic transit times in the pipeline) in a bottle roll apparatus or other agitation vessel, the samples will be allowed to sit, and the decant solution will be separated from the residual solids. Additional fluid will be expressed by pressure filtration from the tailing solids, and those solutions mixed with the decant fluid. The solids will then be allowed to dry at room temperature.

The samples will be analyzed as follows:

- Dissolved constituents (Table 1) in the water and total metals from the solid fraction following the four-acid digestion the solid sample (Table 2 metals).
- Synthetic precipitation leach of the solids at a water:solids ratio of 4:1. The leachate would be analyzed for the Table 1 constituents.
- Acid/base accounting on the solid sample including Sobek NP; total C and S by Leco furnace; C and S by Leco furnace after HCL leach.
- Kinetic Net Acid Generation (NAG) testing on the solid sample. At the completion of the test the liquid should be analyzed for dissolved constituents (Table 1 constituents), and the solid sample should be analyzed for total metals following four-acid digestion.
- Splits of ten of the samples will be tested using the selective extraction procedures, as described above.
- Approximately five pairs of samples (selected on the basis of results of tests 1 through 4) also would undergo humidity-cell testing (KEL Method 5011.02) for a nominal 20 weeks; if results over that period justify it, testing of selected samples may continue. The "pair" for each sample would be a split of the tailing before reaction and a split of tailing after reaction.

Because standard humidity-cell tests to date on KUCC tailing have shown little or no evidence of significant reaction, we anticipate modifying test procedures to improve the likelihood that these tests would produce useful data. Three modifications are under consideration at this time:

- Accelerate the drying of tailing to ensure that air can circulate freely through the tailing between rinse cycles. This might involve both increasing the temperature and mixing the tailing charge to ensure that low moisture content is achieved in the initial phase of each test cycle.
- Subject the tailing charge to vacuum extraction after drain-down in each cycle (e.g., Lapakko, 1994). As with temperature-drying, vacuum drying would remove residual moisture and allow flow of air through the tailing solids.
- Run the entire humidity-cell test at elevated temperature to increase reaction rates. The rate of pyrite oxidation is expected to approximately double for each 10 °C increase in temperature (e.g., Pauling, 1970). Therefore increasing the temperature of reaction from approximately 20 °C (room temperature) to 60 °C would be expected to increase reaction rates by a factor of approximately 8. This rate increase may allow the humidity-cell test to simulate very long reaction periods, but the temperature increase should not

be so great as to compromise the viability of the resident microorganisms. The relationship of the high-temperature tests to field temperatures can be evaluated by using known activation-energy relationships for abiotic pyrite oxidation. Similarly, the effects of increased temperature on depletion rates of NP can be evaluated by considering the known relations of carbonate and silicate solubilities as functions of temperature across the experimental range.

- Mineralogical analysis on the five, post-reaction samples selected for kinetic testing.

#### **4.2.2 Dynamic Testing in Tailing Pipeline**

At five times over the RD Study (coordinated with (a) KUCC Geology and Mine Planning to represent a range of ore mixtures and (b) known changes in aqueous flow chemistries), the KUCC team will analyze changes in chemistry and mineralogy at standard stations down the length of the pipeline. The Source-Term Characterization sampling will be coordinated with these events to ensure that the chemistry of all fluids and the chemistry and mineralogy of tailing solids prior to reaction are well documented. The points of evaluation are expected to be:

- Sources (see above);
- BCP2750, in the tailing line below the thickeners but above input of water-treatment concentrates;
- NP-6 after combination with concentrates (BYP2535);
- Splitter Box (MCP2536);
- West Discharge Cyclone (overflow and underflow).

At the time of each sampling run, a standard charge of Li will be added to the water-treatment concentrates to serve as a conservative tracer of flow in the tailing line. An initial set of Li-tracer tests will be run to evaluate transit time in the pipeline.

At each station, four samples will be collected at intervals and over a total time period to be determined on the basis of the initial Li-tracer testing at each station from BCP2750 to the West Discharge Cyclone station.

At each slurry-sampling point, samplers will collect coexisting water and tailing solids for analysis. Aqueous phase analyses will be for the parameters shown in Table 1, plus Li. Solid-phase chemistry will be for parameters shown in Table 2, including acid-base accounting parameters. In addition, at each station, one sample of tailing solids will be obtained for mineralogical evaluation. The mineralogical analyses for the reacted samples will be the same as those for the source tailing.

**[For KUCC Review; not to be included in work plan submitted to EPA/State:** In addition, based on those mineralogical evaluations, Dr. Jambor and Mr. Logsdon may select specific samples for advanced spectroscopic analyses of surfaces to document the nature of secondary reactions (e.g., precipitation, co-precipitation or adsorption) that represent the specific mineralogical mechanisms for metals removal from aqueous to

solid phase. The surface methods would be selected after initial mineralogical evaluations, and, if suitable phases and evidence of surface phenomena are present, may include x-ray photoelectron spectrometry (XPS), time-of-flight / laser ionization mass spectrometry (TOF-LIMS), or other suitable methods for evaluating surface phenomena. At this time, approximately 20 samples of reacted solids over the course of the entire study would be subjected the selective extraction procedures and then examined in the surface analyses. For each of these samples, there would be examination of approximately 10 surface locations tested.]

In addition to these dynamic tests, the KUCC team will collect approximately five samples of pipeline scale to evaluate its mineralogy and chemistry. Mineralogical analyses will include the methods (i.e., optical, XRD and electron beam) described above, and samples will be analyzed by selective extractions and total digestion.

Field-scale, very long-term testing of tailing that have discharged from the pipeline is discussed below.

#### 4.3 HYDROGEOCHEMICAL MODELING OF THE PIPELINE REACTOR

The geochemical and mineralogical data of the RD Study will be used to develop and calibrate a one-dimensional, flow-and-reactive-geochemical model for the tailing pipeline reactor. The basis for this evaluation of geochemical reaction in the pipeline is expected to be the approach used in the hydrogeochemical model MIN3P (Mayer, 1999). In this model, one specifies fluid chemistry and detailed mineralogy of inputs, and the code uses either equilibrium or kinetic expressions to model mass transfer (including mineral precipitation and dissolution) over time along a quantitative flow path. MIN3P is well suited to the geochemical issues of the KUCC system because it is designed to operate with variably saturated flow systems (i.e., could be used to evaluate the vadose zone of the tailing impoundment as well as the pipeline) and explicitly addresses gas flow and its mass-transfer implications. These modeling capabilities are not present in other geochemical computer programs, like PHREEQC. Evaluation of the specific model, or perhaps modifications to MIN3P, will account for the moving solids in the slurry, also. [Professor Ulrich Mayer, who developed MIN3P, is in the Department of Earth and Ocean Sciences, University of British Columbia. His *curriculum vitae* is attached.]

When a suitable hydrogeochemical model is available, KUCC will be able to make use of projections of future inputs of both tailing (developed by calibrating the tailing mineralogy to ore feeds during the RD Study) and water-treatment concentrates (developed from operational history of the water-treatment system and the ongoing modeling of the groundwater plume extraction system) to forecast the geochemical impacts of the operational period on both decant solutions and tailing solids. Ownership of the computer model MIN3P or its derivatives will remain with Professor Mayer. It seems likely that, following the detailed evaluations using MIN3P, it will be possible to develop a subset of reactions that can be programmed into a relatively simple, one-dimensional flow model (representing the pipeline) to produce a modeling tool that Kennecott can use efficiently to evaluate the pipeline system during operation.

In addition to MIN3P, KUCC will evaluate other modeling options, including models developed in the chemical engineering industry.

#### 4.4 GEOCHEMICAL EVOLUTION OF TAILING IN THE IMPOUNDMENT

Because discharge to the tailing impoundment from the cyclones and the peripheral discharge line is continuous, there is no practicable way to monitor long-term tailing weathering on the active portion of the tailing impoundment. Additionally, the new discharge system and the addition of water-treatment concentrates implies that the Old Tailing Impoundment is not a good surrogate for weathering of tailing that will occur during and after the Remedial Action. Therefore, we propose to construct a set of test cells of new tailing that can be monitored over long periods (several years or more) to evaluate the long-term geochemical stability of the tailing during ambient weathering.

KUCC will construct two, separated test cells, each with a surface area of approximately 1 acre. One cell will be filled with tailing from a high-carbonate / low-quartzite ore mixture, and the other cell with low-carbonate / high-quartzite tailing. The tailing will be collected at the West Cyclone Station, transported to the test-cell location, and placed in the test cell using a small-scale cyclone apparatus to produce an "embankment" height of 3m (10 feet). The gravity flow of the tailing will generate a slope equivalent to that in the current impoundment. Decant solution will be pumped back to the tailing return system. After initial drainage of the tailing, standard KUCC revegetation methods will be used on the surface of the test cells, (a) to control dust; (b) to serve as long-term, experimental test plots for revegetation, and (c) to establish evapo-transpiration conditions that will be typical of long-term KUCC tailing.

In each cell, we will establish three transects from embankment to toe, with four sampling zones per transect. Along the central transect, the cell will be constructed to include standard KUCC suction lysimeters. Details of the lysimeter placement will be determined and documented during construction of the cells, based on physical conditions of the tailing and field observations. Nominally, four sets of lysimeters would be placed at depths of approximately 0.5m, 1.0m and 1.5m below top-of-tailing, in a manner consistent with current KUCC lysimeter placements. At the location of each lysimeter, the field team installing the lysimeters will collect samples from the tailing adjacent to the lysimeter screens. These samples will be tested for acid-base parameters and solid-phase chemistry by the selective extraction procedures described above. Splits of the samples will be maintained for mineralogical analysis, if needed. This characterization program will help KUCC interpret solution chemistry when water begins to accumulate in the lysimeters.

Fluid samples will be collected quarterly in each lysimeter, assuming sufficient sample volume to collect and analyze. In addition, twice per year, KUCC will collect tailing at each of the twelve sampling zones. For each event and at each station, a sample will be a nominal 1m-long core (5cm ID). The moisture content and matric potential of the core will be evaluated at 20 cm intervals. On splits of the sample, pore water will be expressed from each 20-cm interval, and the tailing solids will be evaluated using selective extractions and also mineralogical analyses.

#### 4.5 SIMULATION MODELING OF THE TAILING DISPOSAL SYSTEM

We anticipate using a Monte-Carlo – type, systems simulation model to examine overall system behavior, including return flow chemistry to the make-up pond at the Copperton Concentrator. The simulation model we expect to use is either the current KUCC simulation model, STELLA, or an equivalent code. Note that, as above, MIN3P and its derivatives, if incorporated into the tailing-system simulation model, would not become property of either Kennecott, MM High Performance Systems, Inc. or any other party unless properly executed licensing agreements are executed with Professor Mayer.

#### **5.0 SCHEDULE**

The basic technical work of the Remedial Design, including the geochemical investigations, will begin in the second Quarter of CY 2001 and finish during the fourth Quarter of CY 2002. It is probable that some long-term monitoring programs associated with the investigations (particularly the long-term, tailing test cells) would continue into the Remedial Action phase.

## 6.0 QUALITY ASSURANCE

### 6.1 Quality Assurance Project Plan

The Quality Assurance Project Plan (QAPP) for the Groundwater Characterization and Monitoring Plan (Kennecott, 1999) will apply to all analytical work conducted under this geochemical work plan.

### 6.2 Third-Party, Expert Review: Professor David Blowes (University of Waterloo, Ontario, Canada)

Kennecott is considering a proposal by Mark Logsdon that the geochemical investigations for remedial design be used as the technical basis of a Ph.D. dissertation in the Department of Earth Sciences at the University of Waterloo (Waterloo, Ontario, Canada). Mr. Logsdon's thesis advisor would be Professor David Blowes [*curriculum vitae* attached]. Dr. Blowes is an internationally recognized expert on mining geochemistry and geochemical modeling, and he has worked on many problems involving both groundwater contamination at mines and the geochemical evolution of tailing systems. He has worked often with Dr. John Jambor, nominated above to direct the detailed mineralogical evaluations (e.g, Blowes and Jambor, 1994). Dr. Blowes already is familiar with the Bingham Canyon mine and its waste-management issues, having participated in third-party reviews during the RI/FS process and other interactions with Kennecott and Rio Tinto.

This approach will allow on-going, highly expert, third-party review of the RD work through the research supervision and the technical interactions between Logsdon and Professor David Blowes. Professor Blowes would come to Kennecott for a one-week site review twice per year. In addition, Logsdon would go to Waterloo to review data and progress on evaluating the system two additional times per year (i.e., in alternating Quarters). Based on their past cooperation on projects in mining geochemistry, it is expected that there will be very regular communications between Mr. Logsdon and Dr. Blowes by telephone and e-mail throughout the project in addition to the quarterly reviews. Dr. Blowes' oversight effort on this project is estimated to be 300 hours over two years.

In addition to Professor Blowes' supervision of research, the proposed project will use the expert services of Dr. Jambor (who also is an adjunct Professor at University of Waterloo) for mineralogy and Professor Mayer for reactive geochemical modeling.

## 7.0 REFERENCES

Blowes, D.W. and J.L. Jambor (Editors), 1994. *The Environmental Geochemistry of Sulfide Mine-Wastes*. Mineralogical Association of Canada, Short-Course Handbook Vol. 22 (May, 1994), 438 p.

Ficklin, W.H., A.H. Love, and C.S.E. Papp, 1991. Solid-phase variations in an aquifer as aqueous solution changes, Globe, Arizona: in G. E. Mallard and D.A. Aronson (Eds.), U.S. Geological Survey Toxic Substances Hydrology Program – Proceedings of the technical meeting, Monterey, California, March 11-15, 1991: U.S. Geological Survey Water-Resources Investigations Report 91-4034, p. 475-480.

Lapakko, K.A., 1994. Subaqueous disposal of mine waste: A laboratory investigation. In Proceedings of Third International Conference on the Abatement of Acidic Drainage, April 25-29, 1994, Pittsburgh, PA, Vol. 1, p. 270-278.

Mayer, K. U., 1999. *A numerical model for multicomponent reactive transport in variably saturated porous media*, Ph.D. thesis, University of Waterloo, Department of Earth Sciences, Waterloo, Ontario, Canada.

Parkhurst, D.L., 1995. User's Guide to PHREEQC – A Computer Program for Speciation, Reaction-Path, Advective-Transport, and Inverse Geochemical Calculations: U.S. Geological Survey Water-Resources Investigations Report 95-4227, 143 p.

Linus Pauling, 1970. *General Chemistry*. New York, Dover Publications, Inc. / San Francisco, W.H. Freeman, 959 p.



Table 1. Aqueous-Phase Chemistry (method detection limits (MDL) in mg/L, except pH in su, Conductivity in uS/cm, and Alkalinity/Acidity in mgCaCO<sub>3</sub>/L); Methods are EPA numbered, except SM: Standard Methods and Fe<sup>2+</sup> by colorimetric field test. Target Detection Limits from Kennecott, 1999 (QAPP for GCMP)

Class	Parameter	Method	Target Detection Limits
<i>General</i>			
	pH	150.1	Not applicable
	Conductivity	120.1	10 uS/cm
	Alkalinity	310.1	10 mg CaCO <sub>3</sub> /L
	Acidity	SM 2310B	10 mg CaCO <sub>3</sub> /L
	TDS	160.1	10 mg/L
	TSS	160.2	3 mg/L
<i>Major Ions</i>			
	Ca	200.7	1 mg/L
	Mg	200.7	1 mg/L
	Na	200.7	1 mg/L
	K	200.7	0.1 mg/L
	HCO <sub>3</sub>	SM Nomograph	10 mg/L
	CO <sub>3</sub>	SM Nomograph	10 mg/L
	Cl	352.2	5 mg/L
	SO <sub>4</sub>	375.2	5 mg/L
<i>Minor Species</i>			
	SiO <sub>2</sub>	6010B	2 mg/L
	Sr	200.7	1 mg/L
	F	340.2	0.2 mg/L
	Ortho-PO <sub>4</sub> (P)	365.1	0.1 mg/L
	NO <sub>3</sub> +NO <sub>2</sub> (N)	350.1	0.2 mg/L
<i>Metals and Metalloids</i>			
	Al	200.7	0.2 mg/L
	As	200.7	0.005 mg/L
	Ba	200.7	0.01 mg/L
	Cd	200.7	0.002 mg/L
	Cr	200.7	0.01 mg/L
	Co	200.7	0.05 mg/L
	Cu	200.7	0.02 mg/L
	Fe (total)	200.7	0.3 mg/L
	Fe <sup>2+</sup>	Field Kit	0.1 mg/L
	Hg	245.5	0.0002 mg/L
	Mn	200.7	0.01 mg/L
	Mo	200.7	0.003 mg/L
	Ni	200.7	0.03 mg/L
	Pb	200.7	0.005 mg/L
	Se	7742 (Mod) [Hydride]	0.003 mg/L
	Zn	200.7	0.01 mg/L

Table 2. Solid-Phase Chemistry (Method Detection Limits (MDL) in parts per million (ppm), except paste-pH in su, paste-C in uS/cm, ABA-S and -C values in wt%, Neutralization Potential in gCaCO<sub>3</sub>/kg)

Class	Parameter	Method	Target Detection Limits
<b>General</b>			
	Acid:Base Accounting:		
	Paste-pH	KEL 5010.6	Not applicable
	Paste-Conductivity	KEL 5010.6	10 uS/cm
	Total S	KEL 5010.6	0.01 wt%
	SO <sub>4</sub> - S	KEL 5010.6	0.01 wt%
	Neutralization Potential	KEL 5010.6	1 g CaCO <sub>3</sub> /kg
	Total C	KEL 5010.6	0.01 wt%
	Total C after HCl leach	KEL 5010.6	0.01 wt%
<b>Metals and Metalloids</b>			
	Al	6010B	
	As	6010B	
	Ba	6010B	
	Cd	6010B	
	Cr	6010B	
	Ca	6010B	
	Co	6010B	
	Cu	6010B	
	Fe	6010B	
	Pb	6010B	
	Mg	6010B	
	Mn	6010B	
	Mo	6010B	
	Ni	6010B	
	Na	6010B	
	Se	6010B	
	Sr	6010B	
	Zn	6010B	